Chinese Journal of Electronics
Vol.27, No.5, Sept. 2018

# RectMap: A Boundary-Reserved Map Deformation Approach for Visualizing Geographical Map*

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**Abstract — Spatial visualization has always been a primary part of information visualization and analysis, especially in the era of big data. The map, the most fundamental components of spatial visualization, is a kind of simple, intuitive and popular way to show the visualization of geographic information. The traditional map is not convenient to overlay complex elements due to its own complex filled color and the actual geographical boundaries. We aim to cut off dusty foliage of the maps, and deliver the main structure of the map visualization result. We proposes RectMap, a boundary-reserved map deformation approach for visualizing geographical map, which can maintain the mind map of original map. The proposed approach integrate traditional Douglas-Peucker algorithm and our Gridding algorithm. The Douglas-Peucker algorithm generates a simplified map, and the Gridding algorithm optimizes the initial simplified map. Case study and user study are further conducted to demonstrate the effectiveness and usefulness of the new-style map.**

**Key words — Map form transformation, RectMap, Map generalization, Gridding.**

## I. Introduction

Due to the popularization of deployment of GPS, massive information is accompanied by geographical and temporal data, specially in the era of big data[1]. Time and space both are necessary factors to describe events[2]. Spatial visualization[2,3] is used to express spatial information and attribute changes of geographical phenomena in a visual way, and has been an irreplaceable role for the fully display of the geographical data. Thus, to facilitate a convenient understanding of complex geographical phenomena, presenting a handy and friendly visualizaiton of geographical data is crucial.

Spatial information is generally overlaid on the map for visual design and display[4]. Map has been the most fundamental components in spatial visualization, which is used to display a large number of geographic location-related data information, and favoured by the majority of big data visualization researchers[5]. Many researchers take the map as a base map, and overlay a large number of information on it, such as traffic data[6], air information data[7] and social network data[8].

However, existing form of map is difficult to overlay information or compare different areas on the map due to following reasons. Firstly, due to the characteristic of irregularity of the map, traditional maps do not allow users to overlay information in a orderly way. For example, if a user wants to overlay bundles of words onto a irregular area, the text may be wrapped into several rows with different length, which increase the difficulty in reading the words. Secondly, existing methods like map deformation techniques aims to deform the map to present information more vividly. Cartogram is widely used in GIS area to present value by the size of area, but it still causes irregularity to the deformed map, which still suffered by the overlay issue. Another option is the Spatially ordered treemaps technique proposed by Wood *et al.*[9], which transformed each area of the map into a rectangular grid, and the relative position of grids correspond to the original position of the geographical map. This technique successfully solves the irregularity issue of the map boundary, however, the grid is based on basic rectangle, thus the grid cannot better reflect the original boundary line of different map areas.

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*Manuscript Received Mar. 16, 2017; Accepted Aug. 28, 2017. This work is supported by the National Natural Science Foundation of China (No.61602409), Zhejiang Provincial NSFC (No.LR14F020002), joint project Data-Driven Intelligent Transportation between China and Europe announced by the Ministry of Science and Technology of China (No.SQ2013ZOC200020), and the Open Projects Program of Key Laboratory of Ministry of Public Security based on Zhejiang Police College (No.2016DSJSYS003).

DOI:10.1049/cje.2017.12.003

In order to address above challenges, we propose RectMap, a boundary-reserved map deformation approach to visualize geographical map. RectMap remains the original geographical boundary information of the map, which is not only aesthetically pleasing and legible, but also provides considerable space to support users overlay information. We formulate the creation of RectMap through using a novel strategy with a judicious combination of Douglas-Peucker algorithm[10] and Gridding algorithm[11]. The Douglas-Peucker algorithm generates a simplified map through reducing the points and straightening the geographical boundaries, while the Gridding algorithm transforms the map into a regular and rectangular shape similar to the original region through dividing map into several rectangles related to the actual geographical region. We further evaluate our algorithm against the spatially ordered treeemaps proposed by Wood. To provide its effectiveness during the process of linking deformed map with original geographical map.

Specifically, we make the following contributions:

1) We proposed a new efficient approach that can transform the geographical map into a rectangular one while preserving the original geographical boundary characteristic of the map.

2) We adopted real-world geographical maps to evaluate the usefulness of our methods, and presentd scenarios of overlaying geo-referenced information.

3) We conducted a user study that evaluate the effectiveness of our methods for linking deformed map with original geographical map.

## II. Related Work

### 1. Spatial visualization

Considerable research has been directed towards demonstrating spatial data to illustrate the connection between event and spatial data. Researchers have proposed many spatial data visualizations such as Heatmap and its extension[12]. In Ref.[12], Meier *et al.* generated and delivered web-based heatmap visualizations for spatial data that is optimized for mobile devices. Sun *et al.*[13] presentd a novel visualization technique called route-zooming that can embed spatio-temporal information into a map seamlessly for occlusion-free visualization of both spatial and temporal data. Anselin[14] reviews the ideas behind interactive and exploratory spatial data analysis and their relation to GIS. Although using 3D maps or heatmaps can do a good job of illustrating the spatial information for the specified location, these methods often fail to show large amounts of information on the map intuitively due to small space. In recent years,Andrienko *et al.*[15] raised the requirement of find and overlaying effective visualizations of spatio-temporal dimension information in geospatial data. Our work aims to provide an efficient approach for user to conveniently overlay spatio-temporal information in geospatial data. Li *et al.*[16] although analyzed a lot of air quality data in Beijing, but only on the map with a heatmap to do the PM2.5 color mapping. So that other air indicators with a variety of visual components to show, if the map has enough space to place other indicators visual view, that will be more user-friendly.

### 2. Map generalization

Map generalization is an emerging topic in computer graphics. Its main task is to simplify the map to highlight the contents of the specified topic. In some cases, less is more. Thus, for certain geographical maps, by removing unimportant trivial details, we can better display important subject information better.

Cartograms are a well-known technique for showing geography-related statistical information, such as population demographics and epidemiological data. The basic idea is to distort a map by resizing its regions according to a statistical parameter, but in a way that keeps the map recognizable. In recent years, Keim *et al.*[17] dealt with the problem of making continuous cartograms that strictly retain the topology of the input mesh. Hennig *et al.*[18] used a cartogram to represent population distribution at the province level in 2010. The cartogram effectively demonstrates that population is unevenly distributed across the different parts of China.

Regarding the geometry-based shape deformation, Douglas-Peucker algorithm reduces the number of points required to represent the line and polygon. Peng *et al.*[19] ensure topological consistency during continuous generalization of map through an optimization algorithm. Based on their idea, we propose a boundary-reserved map deformation approach for visualizing geographical map.

## III. Rectmap Overview

The system input is an JSON file containing boundary data of many administrative regions. Each region boundary consists of a large number of geographic boundary points, together with many other attributes, such as region ID, region name *et al.*.

To create a map with the same relative location to the realistic geography position as well as simple and aesthetically appealing, we have developed RectMap as Fig.1. The left is traditional map, and the right is our RectMap. The Rect map consists of regular blocks. It can be seen that the corresponding blocks in each region maintain the original relative position, and the shape of the city is similar to the one in the traditional map. Fig.2 illustrates the system overview. For simplicity, we take the Zhejiang Province of China in Fig.1 as an example to illustrate the basic idea of our method. Our method can be easily applied to other city datasets such as France as shown in Section VI.2.

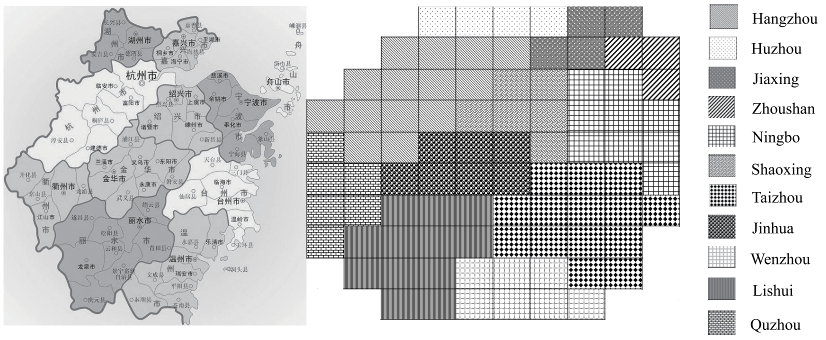


Fig. 1. Comparison between traditional map and RectMap of Zhejiang Province, China

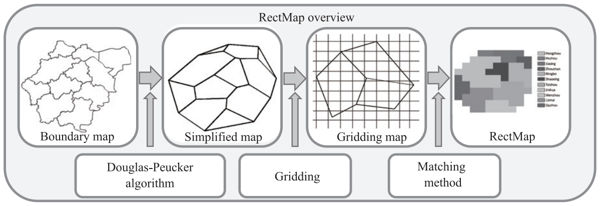


Fig. 2. System overview

The RectMap consists of four steps: extracting geographic boundary data, map generalization, map Gridding and determining the belonging of each rectangle. In the first step, we extract boundary data as the source input data. Then we obtain simplified map through applying Douglas-Peucker algorithm to reduce the points and twists of the original map data. Next, through the Gridding algorithm we divide the map into a rectangle set $R\{R_1, R_2, R_3, \cdots, R_n\}$, based on the simplified map, $n$ is the number of rectangles. Finally, we match each rectangle to the corresponding region, and draw all the rectangle collections of each region to form the RectMap.

## IV. Design Considerations for Rectmap

RectMap aims to generate a legible map visualization as well as ensure actual relative geography. In this section, we introduce our considerations for the visual design.

### 1. Design goals

The following design criterias are used when creating a RectMap visualization:

1) Every different color block represents different region on the map.

2) The shape of the color block indicate the relative shape of the regions on the map.

3) The deformed map should remain users' mind map, namely, the position of block indicate the relative locations of the regions on the map.

Following the above criteria, we could achieve the result of a legible RectMap visualization. Early efforts[9] have achieved a certain amount of success in creating a simple map form. However, it lost the original geographical sense of the relative spatial location. Moreover, the layout method cannot easily add more spatio-temporal information.

### 2. Design constraints

The research[20] shows that the regular rectangles are more aesthetically pleasing than other polygons. In our design progress, in order to ensure the aesthetics and conciseness of the new map, we convert the boundaries of the new map into straight edges, and each corner is converted to a right-angle. We have five design constraints as follows:

1) Ensure that constructed blocks keep the original relative position since we may lose some information when we do the map generalization.

2) Ensure that constructed blocks has a similar shape to the original regions.

3) Ensure that each corner of the block is deformed to right angle so that the final block is a regular shape.

4) Ensure that all the blocks would not coincide.

5) Ensure that there is no blank area between any two adjacent blocks.

In order to satisfy these design constraints, we propose strategies as follows.

### 3. Strategies of design

In our design progress, we have four strategies in generating the desired visualization.

1) Extract real boundary data: make sure the shape generated automatically by our system have the same relative location to the region location in reality.

2) Simplify the map: reduce points numbers and make the line straight between two adjacent points through Douglas-Peucker algorithm. The simplification can reduce the time of Gridding. The process is shown in Fig.3($a$) and ($b$).

3) Gridding: we apply the Gridding according to the points on the simplified map, as shown in Fig.3($c$). The corners of each rectangle that make up the block are at right angle and has no blank area between any two adjacent rectangles. This process ensures every block to be a regular shape and has no blank area with any two adjacent block. Specific implementation is shown in the Section V.2.

4) Determining the belonging of each rectangle: Match

the rectangle to the only corresponding region. Thus, we can ensure the final shape in RectMap is similar to the shape of its corresponding region in real-world and does not coincide with each other. Specific implementation is shown in the Section V.3.

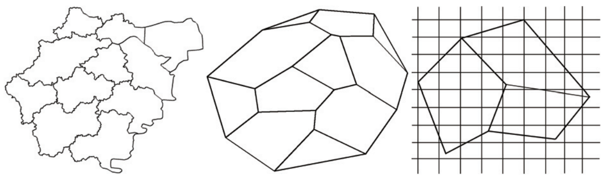
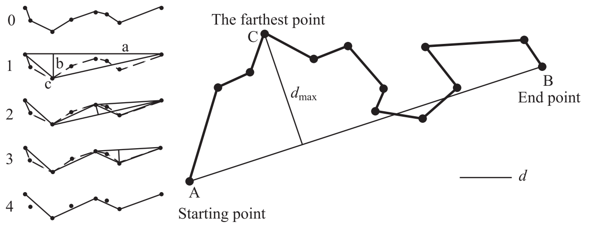

(*a*) (*b*) (*c*)

Fig. 3. The illustration of the process of simplification and gridding. (*a*) Original map; (*b*) Simplified map; (*c*) Gridding

## V. Specific Implementation of Strategies

### 1. Map generalization

We simplify the original map by Douglas-Peucker algorithm since it is an effective approach to reduce points required to represent line simply and representatively. Douglas-Peucker algorithm keeps important points on the basis of comparing the setting threshold $d$ to $d_p$, which is the distance from each point to the line. The larger the parameter $d$ is, the greater the degree of simplicity is. We explain the specific algorithm according to Fig.4.



(*a*) (*b*)

Fig. 4. (*a*) Algorithm flow diagram; (*b*) The schematic diagram of Douglas-Peucker algorithm

Refer to Fig.4, we express this algorithm as follows:

1) Connect starting point A and ending point B to form a straight line AB.

2) Find the the point C on the curve, which is the farthest point from the line AB. The distance $d_p$ is then calculated.

3) If $d_p < d$, the line segment AB is approximated as the curve, and the segment curve is further processed.

4) If $d_p \geq d$, we divide the curve into two sections, *e.g.*, AC and BC, and the two sections are processed by 1) to 3), respectively.

5) When all the curves are processed, the polylines are formed by connecting the individual points in turn, which can be used as the approximation of the curve.

We define $d = 1$ when we simplify the original map, as shown in Fig.3(*a*) and (*b*). We set the input point as the real coordinates on the earth (longitude, latitude). We can see all regions on the simplified map keep the similar shape.

### 2. Gridding

To ensure every block corresponding to its region to be a regular shape, we further conduct the Gridding on the simplified map. To illustrate the Gridding simply, please refer to Fig.3($c$): we draw $m$ vertical lines $V\{v_1, v_2, v_3, \cdots, v_m\}$ and $m$ horizontal lines $L\{l_1, l_2, l_3, \cdots, l_m\}$ in one shape. $m^2$ denotes the number of grids in the shape. Thus, the parameter $m$ could imply the similarity of RectMap and traditional map The larger the $m$ is, the more similar the RectMap and traditional map are. We can find out how $m$ affects the final shape of the RectMap in Fig.5. We illustrate different result with different parameter $m$ of 10, 20, 30, respectively. The larger the $m$ is, the more similar RectMap and traditional map are, which means there are more points and twists.

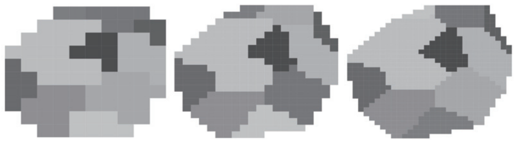

$m$=10 $m$=20 $m$=30

Fig. 5. How $m$ affects the final result

We take every rectangle formed by the adjacent two horizontal lines $l_{i-1}$, $l_i$ and the adjacent two vertical lines $v_{i-1}$, $v_i$ as an element of rectangle set Therefore, all selected rectangle elements do not coincide and all blocks would not coincide. All elements constitute the rectangle set $R\{R_1, R_2, R_3, \cdots, R_n\}$, $n$ is the number of rectangles. The detailed algorithm is as follows:

**Algorithm 1** Gridding algorithm

```
input $m$, then
draw $m$ vertical lines $V\{v_1, v_2, v_3, \cdots, v_m\}$
draw $m$ horizontal lines $L\{l_1, l_2, l_3, \cdots, l_m\}$
sort $V$ from small to big
sort $L$ from big to small
while there has line exists in $V$ do
  for all lines in $L$ do
    form rectangle by the adjacent two horizontal line $h_m, h_{m+1}$ and the adjacent two vertical line $v_n, v_{n+1}$
  end for
end while
construct rectangle set $R\{R_1, R_2, R_3, \cdots, R_n\}$
```

The final block would be regular since the corners of each rectangle that make up the block is at right angle. Moreover, due to the fact that each rectangle belongs to only one block and all rectangles do not coincide, all the blocks would not coincide.

### 3. Determine the belonging of each rectangle

We developed a series of code to determine whether two polygons have an intersection and calculate the area of the intersections. We can then match each rectangle to its corresponding region according to the size of the intersection area. At first, we establish criterion of judging rectangles belonging referring to the Fig.6 as follows:

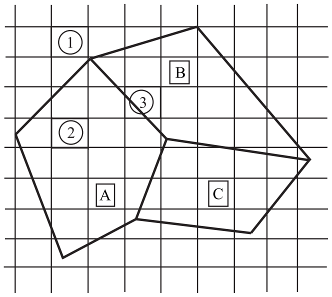


Fig. 6. The illustration of establishing criterion

- Rectangle ① does not intersect with any one region on the map, so we discard this rectangle, since it has no corresponding region.
- Rectangle ② lies in the interior of region $\boxed{A}$, so we match rectangle ② to the region $\boxed{A}$.
- Rectangle ③ intersects with two regions: $\boxed{A}$ and $\boxed{B}$. The intersection area of ③ and $\boxed{B}$ is larger than that of ③ and $\boxed{A}$. So we match rectangle ③ to the region $\boxed{B}$. If one rectangle intersects many regions, we match the rectangle to the region with which the intersections area is the largest.

Specific implementation of this step is as follows:

**Algorithm 2** Matching method

```
for all rectangles in $R$ do
  for all areas on the map do
    if the rectangle has no intersections with any area then
      break
    end if
    if the rectangle intersects the area $A_i$ then
      put the intersection's area to a list
    end if
  end for
  match the rectangle to the area with which the intersection's area is the largest.
end for
draw new map with each area's rectangle set.
```

After above operations, each region is transformed into a block which consists of lots of rectangles corresponding to it.

## VI. Evaluation

In this section, we first use an example to illustrate the usefulness and capability of Rectmap. Then we compare our results with spatially ordered treemap proposed by Ref.[9].

### 1. Case study

We often see block map of house price in modern life. It prints price in one rectangle which stands for one region. However, these block maps almost are drawn by designers through hand drawn or tools with amount of time. Now we can use our method to automatically produce maps like Fig.7. It divided each city of Zhejiang Province into a rectangular block, and the city's average housing prices overlay on the block, so that users clearly know the price of one city and the price distribution relationship. It not only reduces the time spent, but also has similar style as the block map drawn by designers. This case illustrates the usefulness and capability of our approach.

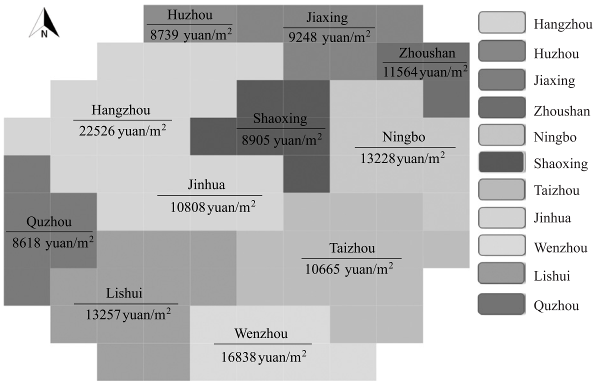


Fig. 7. The application of Rectmap

### 2. User study

We compare our results with spatially ordered treemap to evaluate the performance of our method. We conducted the experiment based on dataset of 20 different maps, such as France, Zhejiang, Qinghai, *etc.* We used the open source code provided by Wood *et al.* to obtain their results.

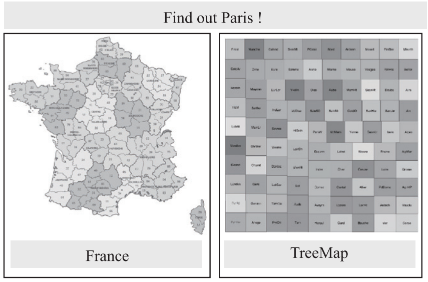


Fig. 8. The experiment interface

**Task and procedure** Each question is shown in Fig.8. Participants were required to choose the right city we gave in Rectmap or spatially ordered treemap as soon as possible. Accuracy and time can expresss the effectiveness of method, so we choose the accuracy and time spent as our main measure indicators.

The study began with a training session in which the participants can familiarize themselves with the system and the task. Considering the accuracy and the time spent of the choice has a lot to do with the position of given city, we divided the cities of the region into three categories:

marginal city, central city, and submarginal city. Marginal city is the city on the edge of the map. Central city is a city located in the center of the map, and the submarginal city is located between the marginal city and the central city. We generated 20 different maps with Rectmap and spatially ordered treemap, and selected three cities of above categories for each map, respectively. The examination questions are sorted randomly to ensure a fair comparison, since if the participant knows the range of the city to be chosen, it will reduce the time it takes to make a choice. Thus, one participant need to perform $20 \times 3 \times 2 = 120$ tests. The entire experiment took approximately 15 minutes to finish, and the participants could rest after finishing one study.

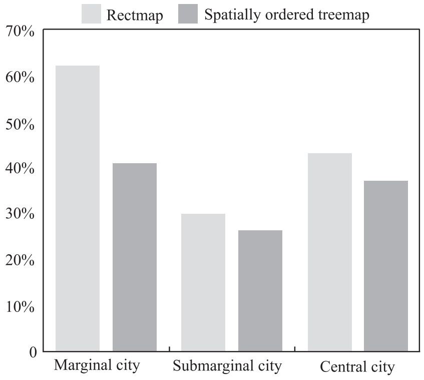


Fig. 9. Comparison of accuracy

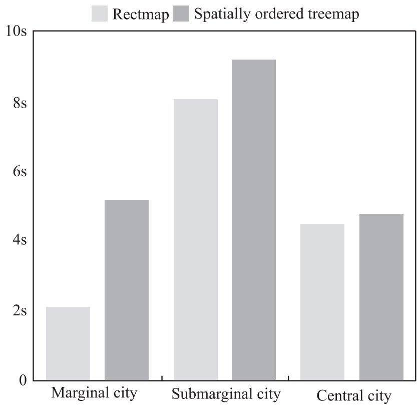


Fig. 10. Comparison of average spent time

**Conclusions** We recruited 20 participants with normal or corrected-to-normal vision. All the participants were undergraduate students, graduate students, or staff in the computer science department of our local university. We show the results in Figs.9 and 10. We can see that Rectmap spent less than 60% of time than spatially ordered treemap on the marginal city, but the accuracy has increased by 50%. We speculate it may be due to the fact that Rectmap maintains the relative position and has a similar shape to the original city for participants to look for. The two methods perform closely on the submarginal city and central city respectively. Moreover, their performance the submarginal city is not good as expected. We speculate that regarding the central city, participants will focus on the range of center, but on the submarginal city there is no reference and the range of submarginal is larger than others. Thus, it is difficult to find the accurate city and will spend more time. From this experiment we can see that Rectmap in maintaining the original location and shape of the region has a certain positive effect.

## VII. Discussion and Future Work

We have presented an efficient approach to generate a RectMap layout which preserves the boundary of the geographical map. The major feature of this approach is that it contains three parts: Douglas-Peucker algorithm to reduce the number of points and twists, Gridding algorithm to make RectMap regular and legible, and Matching algorithm for ensuring high similarity to original map. With the two algorithms, our method can quickly generate a simplified, rectangular and boundary-reserved map.

However, our work still has some limitation. In the future work, we have following work need to do. On major issue is that we now are able to add more elements to the RectMap such as text, time series and other visual components. However, the layout of the texts and time series on the map is still challenging. For example, different blocks has different size, which leads to the difficulty in design reasonable scaling for overlaid time series visualization. Another issue is that the coloring scheme in Rectmap needs to be carefully considered since a successful color scheme can produce a legible visual interface. However, currently most geographical maps use limited color categories to encode different area, adopting similar color scheme in Rectmap may lead to some misinterpretation.

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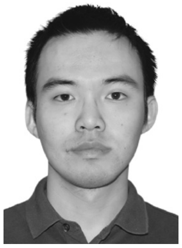

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